FSSC Science Tools

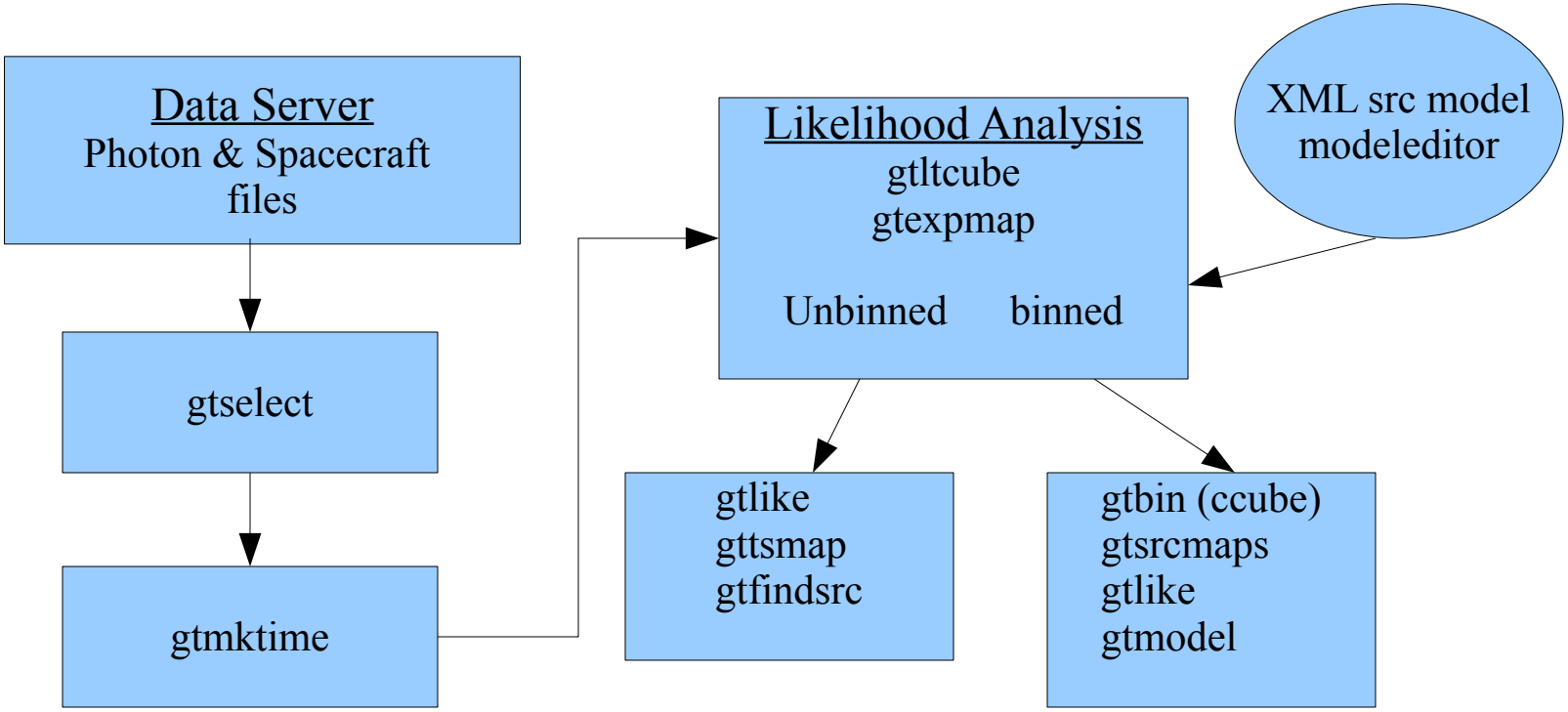
Source Analysis

Likelihood Analysis

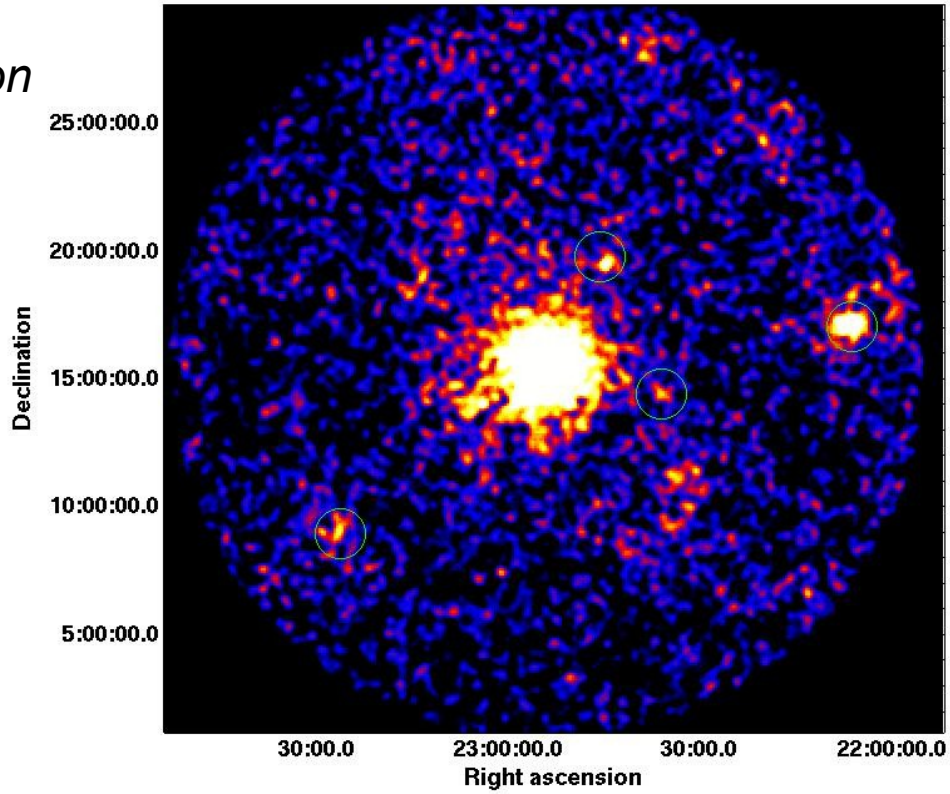
Science Tools: Documentation

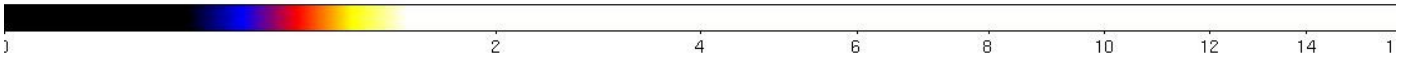
- *Multi-Tier Documentation*
  - *Full set accompanies SW release*
    - *Fermi Mission Technical Handbook*
  - *Multiple levels:*
    - *Detailed analysis description ('Cicerone')*
    - *Individual tool descriptions (like fhelp)*
    - *Analysis threads (cook book examples)*

Science Tools: Overview



- *3c454 region*





Likelihood Analysis

- *Unbinned and binned modes are available. First I'll describe unbinned analysis.*
- *Several tools are needed to define the model and prepare the data*
  - *modeleditor: GUI for preparing the xml model definition file*
  - *gtselect: applies region-of-interest cuts – sky acceptance cone, energy range (0.2 – 300 GeV), time range, zenith angles (< 105^0)*
  - *gtmktime: constructs good time intervals (GTIs) based on pointing information selections, zenith angle cuts and information on the instrument*

Likelihood Analysis (unbinned)

- *gtltcube: integrates LAT livetime as a function of sky position and off-axis angle*
- *gtexpmap: computes RoI-specific exposure maps*
- *gtlike: fits model parameters using maximum likelihood*

- *Details of the method can be found in http://fermi.gsfc.nasa.gov/ssc/data/analysis/documentation/Cicerone*

Likelihood Analysis cont.

You will need a description of the source in your field. This is most easily achieved by using the LAT source catalog and the user contributed script make1FGLxml found at http://fermi.gsfc.nasa.gov/ssc/data/analysis/user/ and comes with a complete instruction manual. This can be run from the python command line or from a python script.

```
from make1FGLxml import *
mymodel=srcList('gll_psc_v02.fit','3c454_100_300000_evt02.fits','srcmdl_01.xml')
mymodel.makeModel('gll_iem_v02.fits','gal_v02','isotropic_iem_v02.txt','eg_v02')
```

- Reads information from your event file (RA, DEC, radius)
- Generates xml model file from the catalog parameters
- Writes this out in a gtlike compatible format sorted by radius

Likelihood Analysis cont.

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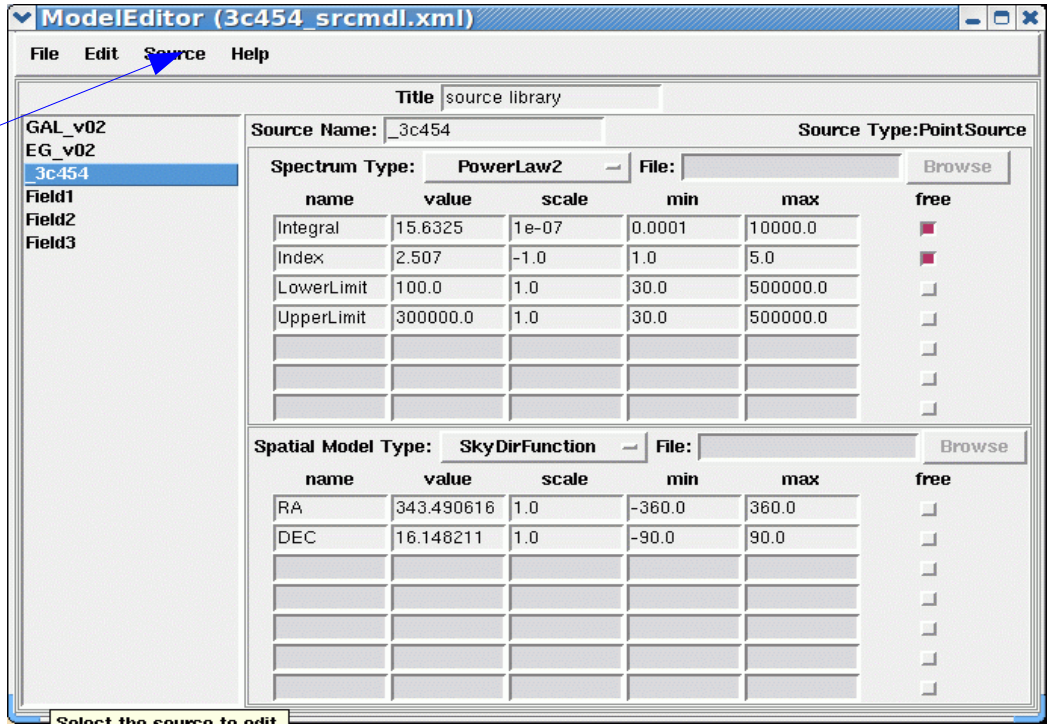
```

- Reads information from your event file (RA, DEC, radius)
- Generates xml model file from the catalog parameters
- Writes this out in a gtlike compatible format sorted by radius

Likelihood Analysis cont.

- *You can edit or adjust your source parameters*
  - *With a text editor*
  - *Using the modeleditor GUI:*

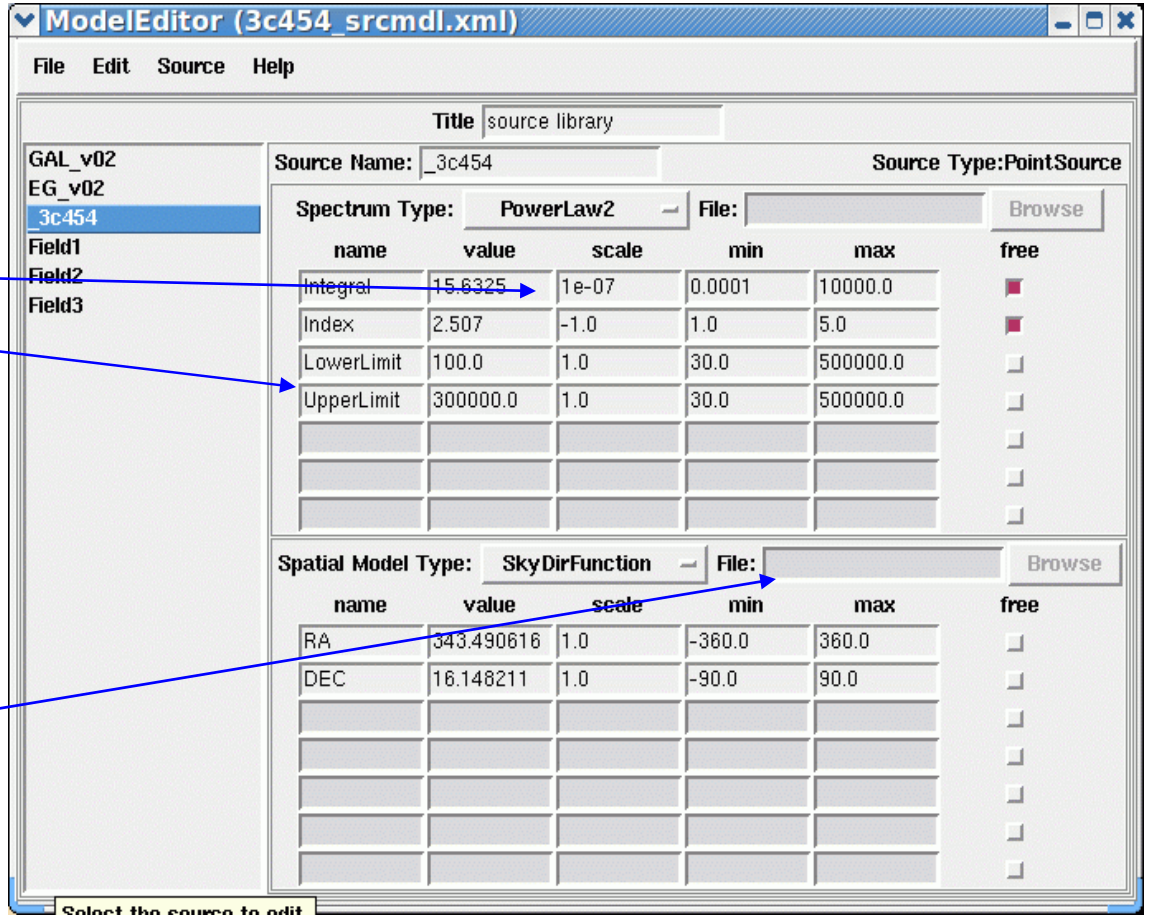
Add sources (point-like or diffuse) using the drop down menu



Likelihood Analysis cont.

Edit source name, default fit parameters, bounds, scaling, etc.

If a model component requires a FITS image (e.g., Galactic diffuse, SNR), enter the filename here



Likelihood Analysis (unbinned)

```
>pset gtmktime evfile=3c454_100_300000_evt01.fits
>pset gtmktime outfile=3c454_100_300000_evt02.fits
>pset gtmktime scfile=3c454_SC00.fits
>pset gtmktime filter="(LAT_CONFIG==1) && (DATA_QUAL==1) \
&& ABS(ROCK_ANGLE)<52."
>pset gtmktime roicut =yes
>pset gtmktime chatter=3
>gtmktime mode=h
>
>
>gtltcube evfile=3c454_100_300000_evt02.fits scfile=3c454_SC00.fits \
outfile=3c454_100_300000_ExpCube.fits
Step size in cos(theta) (0.:1.) [0.025]
Pixel size (degrees)[1]
Working on file 3c454_SC00.fits
.
```

This removes time intervals when the RoI is intersected by the zenith angle cut

Likelihood Analysis (unbinned)

- *gtexpmap*

```
>gtexpmap
The exposure maps generated by this tool are meant
to be used for *unbinned* likelihood analysis only.
Do not use them for binned analyses.
Event data file[] 3c454_100_300000_evt02.fits
Spacecraft data file[] 3c454_SC00.fits
Exposure hypercube file[] 3c454_100_300000_ExpCube.fits
output file name[] 3c454_100_300000_ExpMap.fits
Response functions[P6_V3_DIFFUSE]
Radius of the source region (in degrees)[30] 25
Number of longitude points (2:1000) [120]
Number of latitude points (2:1000) [120]
Number of energies (2:100) [20]
Computing the ExposureMap using 3c454_100_300000_ExpCube.fits
...
```

Source region should exceed extracted region by at least 10 degrees

Likelihood Analysis (unbinned)

- *Finally, running gtlike:*

```
>gtlike
Statistic to use (BINNED|UNBINNED) [UNBINNED]
Spacecraft file[none] 3c454_SC00.fits
Event file[none] 3c454_100_300000_evt02.fits
Unbinned exposure map[none] 3c454_100_300000_ExpMap.fits
Exposure hypercube file[none] 3c454_100_300000_ExpCube.fits
Source model file[] 3c454_srcmdl01.xml
Response functions to use[P6_V3_DIFFUSE]
Optimizer (DRMNFB|NEWMINUIT|MINUIT|DRMNGB|LBFGS) [MINUIT]
…
```

Various output based on the chatter level

This is the xml model file created using the modeleditor GUI

_3c454:
Integral: 15.4831 +/- 0.34482
Index: 2.51106 +/- 0.0208313
LowerLimit: 100
UpperLimit: 300000
Npred: 4428.17
ROI distance: 0
TS value: 10373.7
Flux: 1.55575e-06 +/- 3.44843e-08 photons/cm^2/s

WARNING: Fit may be bad in range [100, 222.696] (MeV)

Total number of observed counts: 28337
Total number of model events: 28337.4

-log(Likelihood): 321444.9494

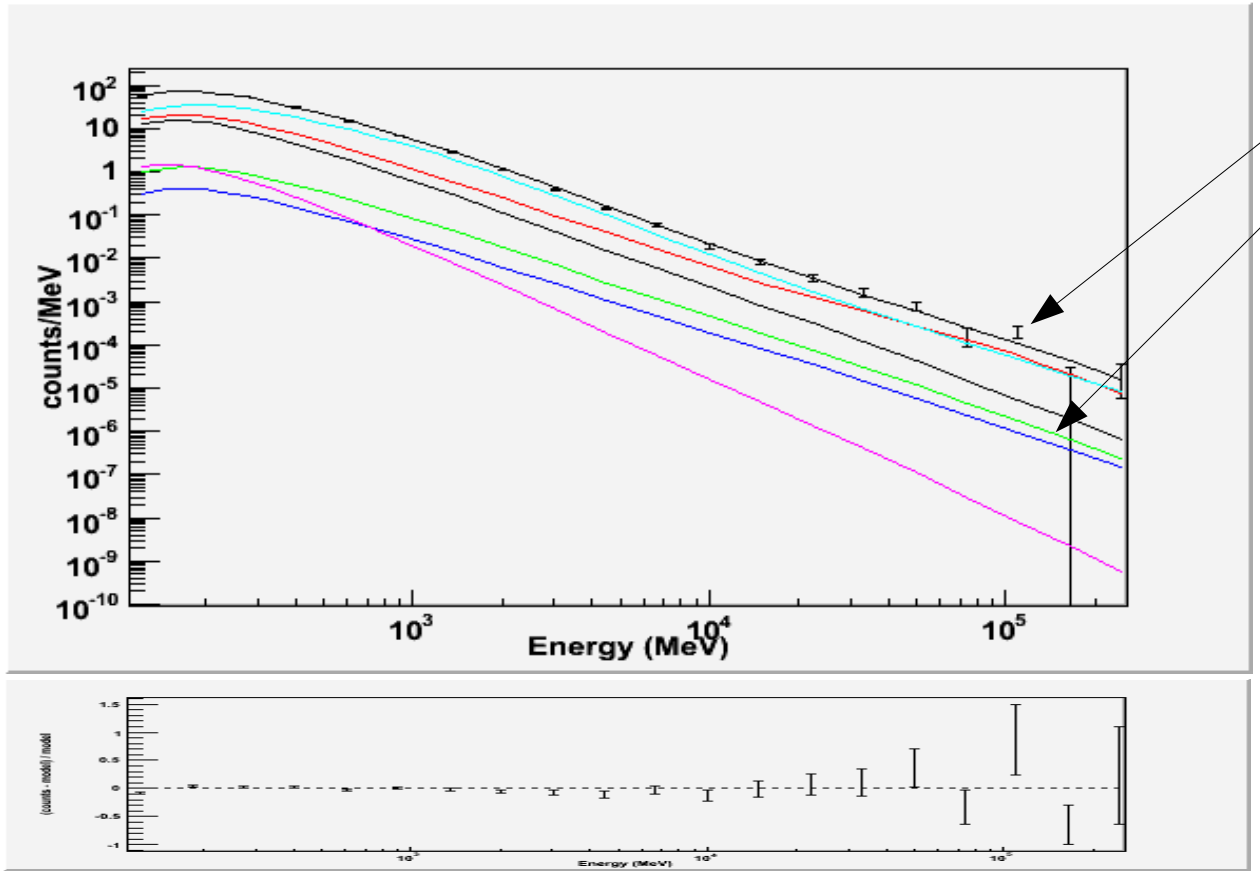
Elapsed CPU time: 53.028839

The Test Statistic (TS) is distributed as χ^2 for n dof. For a power law model TS = 25 is roughly 5σ

Warning messages based on Poisson probability of observed counts given the model prediction in these bands

Likelihood Analysis cont.

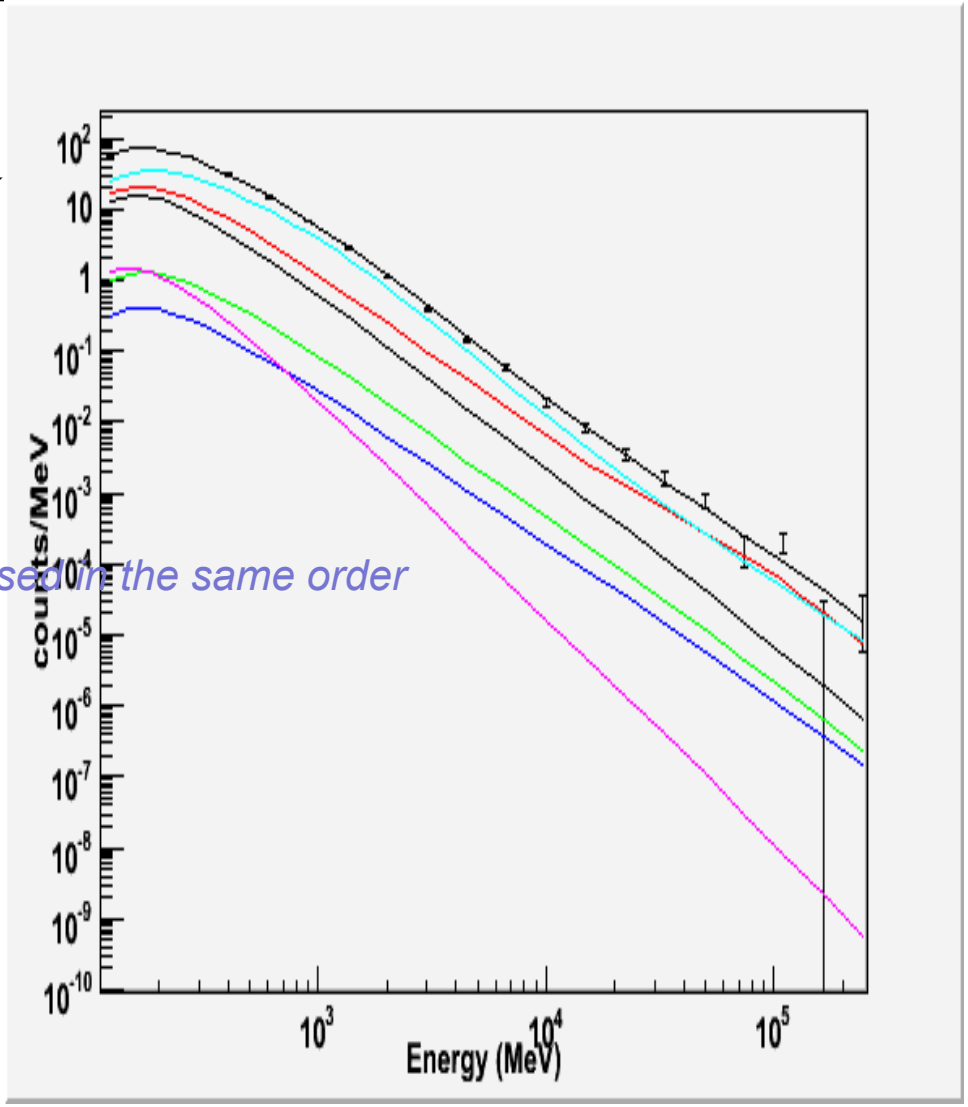
- *Plot the results (gtlike plot=yes)*



The plot shows the counts and the prediction for the Entire field!

Plot Colors

- *The summed model is black*
- *The first source is red*
- *the second, green*
- *the third, blue*
- *the fourth, magenta*
- *the fifth, cyan*
  - *after this the colors are reused in the same order*



How to find missing sources?

How do you determine if you've missed a source?

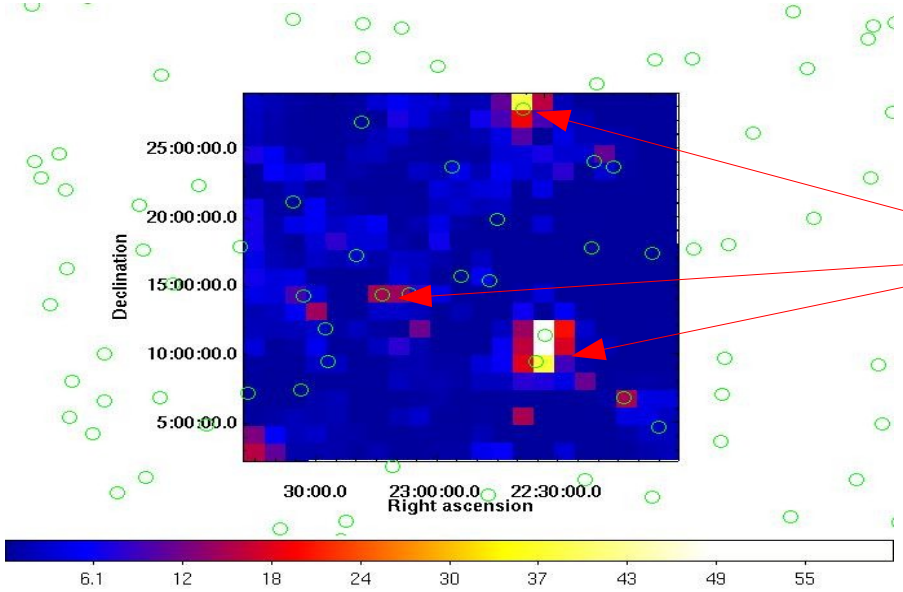
```
>gttsmap
Event data file[] 3c454_100_300000_evt02.fits
Spacecraft data file[] 3c454_SC00.fits
Exposure map file[none] 3c454_100_300000_ExpMap.fits
Exposure hypercube file[none] 3c454_100_300000_ExpCube.fits
Source model file[] 3c454_tsmdl.xml
TS map file name[] 3c454_100_300000_tsmap.fits
Response functions to use[P6_V3_DIFFUSE]
Optimizer (DRMNFB|NEWMINUIT|MINUIT|DRMNGB|LBFGS) [MINUIT]
Fit tolerance[1e-5]
Number of X axis pixels[] 21
Number of Y axis pixels[] 21
Image scale (in degrees/pixel)[] 1.3
Coordinate system (CEL|GAL) [CEL]
X-coordinate of image center in degrees (RA or l)[] 343.490616
Y-coordinate of image center in degrees (Dec or b)[] 16.148211
Projection method (AIT|ARC|CAR|GLS|MER|NCP|SIN|STG|TAN) [STG]
```

Did we Miss anything? Yes!

Besides the spectral plot & residuals you can use the TS maps

This run a test point source & evaluates the TS at every point in the map

Results are a 2-D map showing the deviations from the model



Catalog sources that were missed in the initial model

How to find the source position.

Once you have an acceptable fit how do you determine the source position?

```
>gtfindsrc ra=343.490616 dec=15.0
Event file[] 3c454_100_300000_evt02.fits
Spacecraft file[] 3c454_SC00.fits
Output file for trial points[] 3c454_100_300000_fsrc.txt
Response functions to use[P6_V3_DIFFUSE]
Livetime cube file[none] 3c454_100_300000_ExpCube.fits
Unbinned exposure map[none] 3c454_100_300000_ExpMap.fits
Source model file[none] 3c454_tsmdl.xml
Building source model from 3c454_tsmdl.xml
-log-likelihood of input source model: 321441
Target source name[] _3c454
Optimizer (DRMNFB|NEWMINUIT|MINUIT|DRMNGB|LBFGS) [MINUIT]
Tolerance for -log(Likelihood) at each trial point[1e-2]
Covergence tolerance for positional fit[0.01]
Best fit position: 343.519,  16.1614
Error circle radius: 0.017526
```

Likelihood Analysis

The observed number of counts in each bin is characterized by the Poisson distribution. *L* is the product of the probabilities of observing the detected counts in each bin, n_k, while m_k counts are predicted by the model:

$$L = \mathrm{e}^{-N_{pred}} \prod_k \left(m_k^{n_k} / n_k\right)!$$

If we let n_k 0 or 1 and take the log we get unbinned likelihood

$$\log L = \sum_i \log\left(m_i\right) - N_{pred}$$

Likelihood Analysis cont.

If we do not let n_k 0 and take the log we get binned likelihood

$$\log L = -\sum_i n_b \log(m_b) - m_b$$

Likelihood Analysis (binned)

Data preparation remains as in the unbinned case.
After gtmktime we need to create products for the binned analysis

```
>gtbin
This is gtbin version ScienceTools-v9r18p6-fssc-20101025
Type of output file (CCUBE|CMAP|LC|PHA1|PHA2) [PHA2] ccube
Event data file name[] 3c454_100_300000_evt02.fits
Output file name[] 3c454_100_300000_ccube.fits
Spacecraft data file name[NONE] 3c454_SC00.fits
Size of the X axis in pixels[] 100
Size of the Y axis in pixels[] 100
Image scale (in degrees/pixel)[] 0.2
Coordinate system (CEL - celestial, GAL -galactic) (CEL|GAL) [CEL]
First coordinate of image center in degrees (RA or galactic l)[] 343.490616
Second coordinate of image center in degrees (DEC or galactic b)[] 16.148211
Rotation angle of image axis, in degrees[0.]
Projection method e.g. AIT|ARC|CAR|GLS|MER|NCP|SIN|STG|TAN:[AIT] STG
Algorithm for defining energy bins (FILE|LIN|LOG) [LOG]
Start value for first energy bin in MeV[30] 100
Stop value for last energy bin in MeV[200000] 300000
Number of logarithmically uniform energy bins[] 20
```

We're now creating a 3-d counts map with log energy spacing

Likelihood Analysis (binned)

After the counts cube is done we need to generate a binned exposure map
First generate a livetime cube as before the use gtsrcmaps to create a binned exposure map.

```
>gtsrcmaps expcube=3c454_100_300000_bExpCube.fits \
cmap=3c454_100_300000_ccube.fits srcmdl=3c454_srcmdl01.xml \
bexpmap=3c454_100_300000_bExpMap.fits outfile=3c454_100_300000_srcMap.fits
scfile=3c454_SC00.fits
Response functions[P6_V3_DIFFUSE]
Generating SourceMap for EG_v02.....!
Generating SourceMap for Field1.....!
Generating SourceMap for Field2.....!
Generating SourceMap for Field3.....!
Generating SourceMap for GAL_v02.....!
Generating SourceMap for _3c454.....!
>
```

Note this is a N-dim image with a stack of source maps. One for each source!

Likelihood Analysis (binned)

- *Finally, running gtlike:*

```
>gtlike statistic=BINNED expcube=3c454_100_300000_bExpCube.fits\
? srcmdl=3c454_srcmdl01.xml evfile=3c454_100_300000_evt02.fits \
? scfile=3c454_SC00.fits expmap=3c454_100_300000_ExpMap.fits \
? cmap=3c454_100_300000_ccube.fits bexpmap=3c454_100_300000_bExpMap.fits
Response functions to use[P6_V3_DIFFUSE]
Optimizer (DRMNFB|NEWMINUIT|MINUIT|DRMNGB|LBFGS) [MINUIT]
Generating SourceMap for EG_v02.....!
```

…

Various output based on the chatter level

You can also generate the source maps “on the fly” - they are quick to produce

_3c454:
Integral: 15.3713 +/- 0.707518
Index: 2.52326 +/- 0.75221
LowerLimit: 100
UpperLimit: 300000
TS value: 9596.18
Flux: 1.54458e-06 +/- 7.07552e-08 photons/cm^2/s

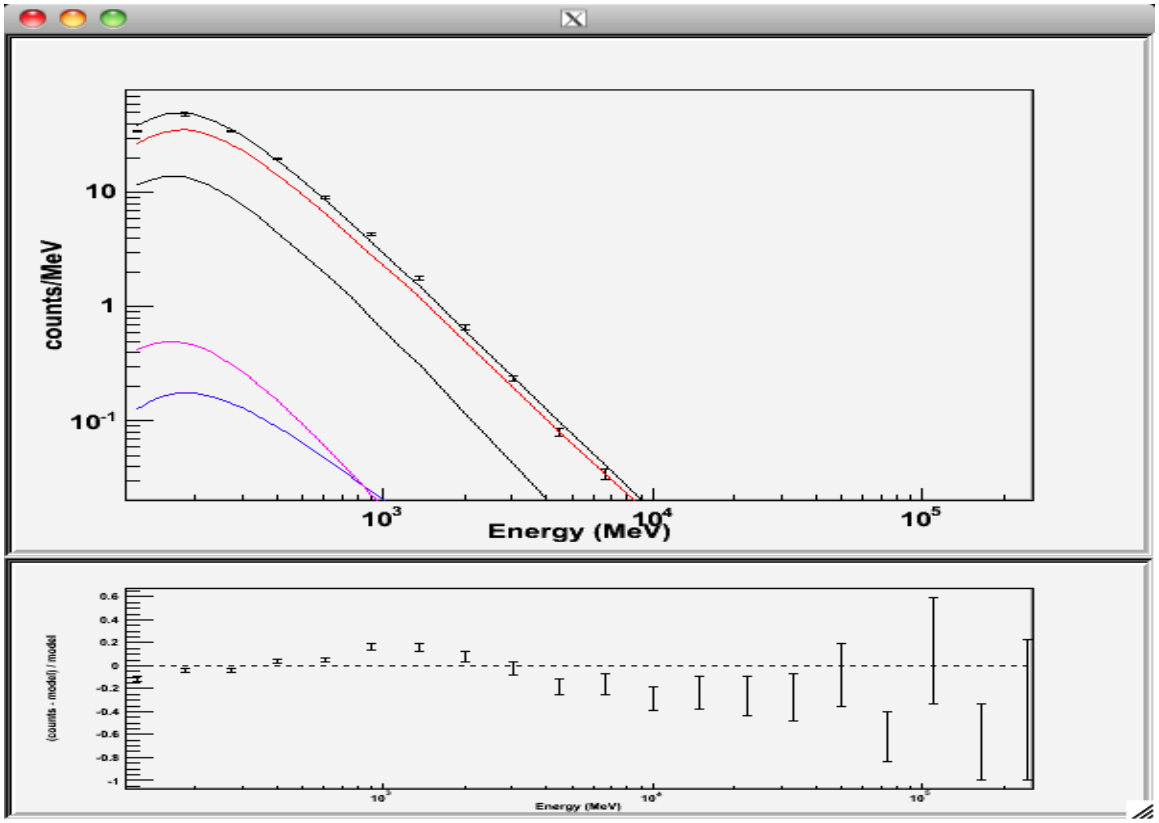
Total number of observed counts: 18178
Total number of model events: 18178.5

-log(Likelihood): 40322.83782

Elapsed CPU time: 131.092388

Likelihood Analysis cont.

- *Plot the results (gtlike plot=yes)*



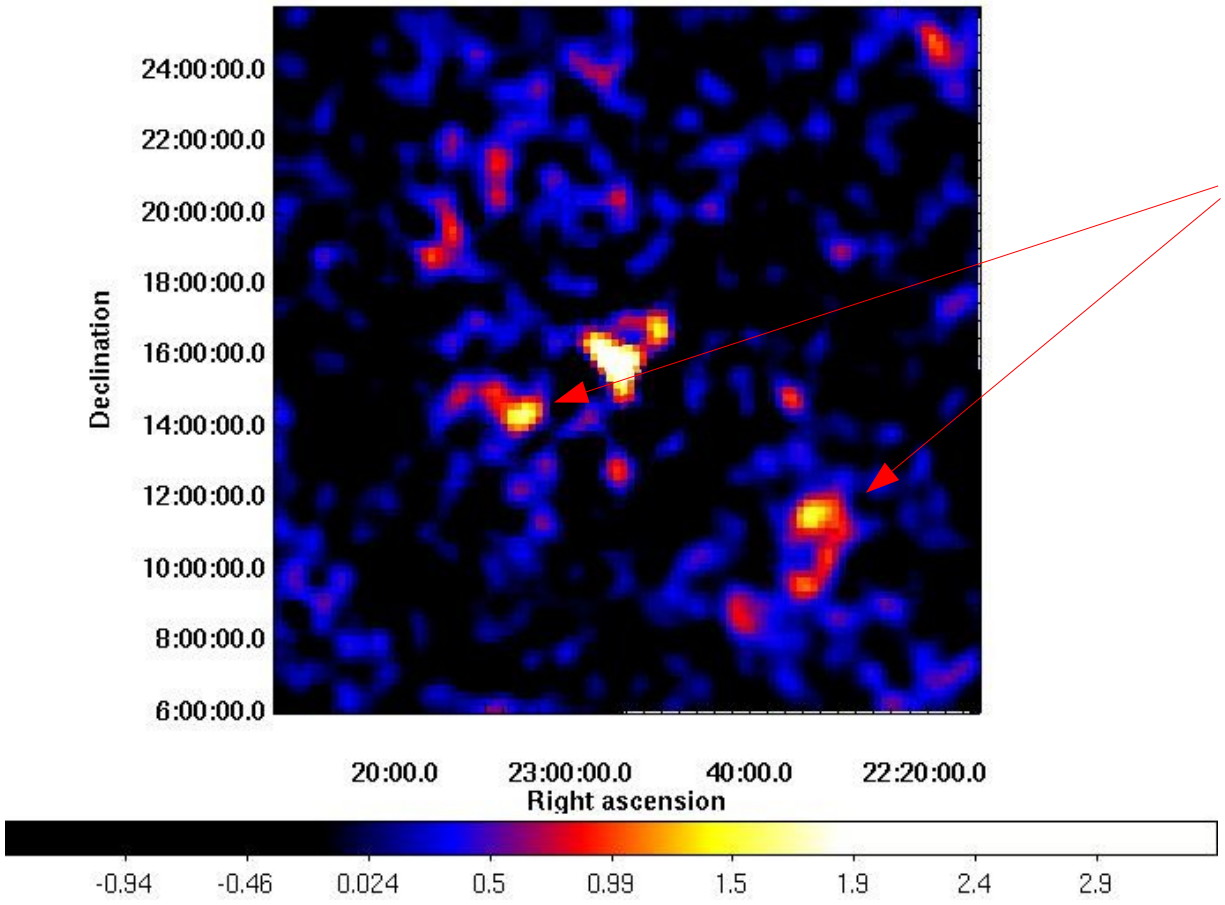
Residual Maps

Once you have an acceptable fit we need to create a model map from the xml file

>gtmodel
Source maps (or counts map) file[] 3c454_100_300000_srcMap.fits
Source model file[] 3c454_100_300000_sfile.xml
Output file[] 3c454_100_300000_model.fits
Response functions[P6_V3_DIFFUSE]
Exposure cube[] 3c454_100_300000_bExpCube.fits
Binned exposure map[none] 3c454_100_300000_bExpMap.fits

farith 3c454_100_300000_cmap.fits 3c454_100_300000_model.fits \
3c454_100_300000_diff.fits SUB

Residual Maps



Some of the same catalog sources that were missed in the initial model